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Scientific Paper

LONGITUDINAL VARIATIONS OF TEMPERATURE, WIND AND ABLATION IN BRØGGERBREEN, SVALBARD

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Abstract: Meteorological observations were carried out on the Brøggerbreen in Svalbard. Longitudinal variations of air temperature, wind speed and ablation were investigated over the Brøggerbreen in summer, 1991. In the middle part of the Brøggerbreen, ablation was observed to be small. In this part of the Brøggerbreen, air temperature was cooler and wind was weak. On the other hand, air temperature and wind speed increased towards the snout of Brøggerbreen and ablation was observed to be large. Although the middle part of Brøggerbreen is affected by the glacier wind system, the lower part is influenced greatly by the wind field in the fjord. The wind speed in the upper part showed the influences of wind blowing over the ridges surrounding the Brøggerbreen. Wind speed in the middle part of the Brøggerbreen was observed to increase when the lapse rate calculated from the temperature difference between the surrounding ridges and the snout of the Brøggerbreen was large.

1. Introduction

The Brøggerbreen is located near Ny-Ålesund in Svalbard. This glacier has many years of data for glacier mass balance. This glacier is important as it offers a record of relationships between glacier and climate in the Arctic (LEFAUCONNIER and HAGEN, 1990). To interpret records of the mass balance as an indicator of climatic change, characteristics of glaciological processes and meteorological influences on the glacier should be investigated. There are some studies on glacial processes in Svalbard by Japanese research groups (NAKABAYASHI *et al.*, 1994; TAKEUCHI *et al.*, 1995; KODAMA *et al.*, 1995); these investigations were done at a single observation point. The present study attempts to investigate spatial variations of meteorological conditions on the Brøggerbreen. This study reports mainly the temperature and wind conditions over the Brøggerbreen.

HAGEN and LIESTØL (1990) reported that the mass balance of the Brøggerbreen is influenced mainly by glacier ablation in summer. Local circulation over the glacier affects temperature and wind conditions, which affect ablation of the glacier. OHATA (1989) studied the structure of the glacier wind in the melting period using a theoretical model considering two air layers over the glacier, that is, the katabatic wind layer and the ambient atmosphere. The ambient atmosphere is outside the thermal effect of the glacier. He showed that the air temperature of the ambient atmosphere and its instability greatly affect the development of the glacier wind (OHATA, 1989). He showed that the effect of atmospheric stability does not work independently, but interacts with the absolute value of air temperature. This study discusses the causes for the fluctuations of wind speed. Since the observations over the Brøggerbreen were limited, these two measures, air temperature and lapse rate, were available for this purpose. Longitudinal differences of air temperature over the glacier indicates local lapse rate; however, the difference of air temperatures observed on the ridges surrounding the glacier and near the glacier snout rather reflect the lapse rate of the surrounding atmosphere. This study compares the longitudinal differences of air temperature over the glacier as local lapse rate and the temperature difference between the ridge and the snout as the lapse rate of the ambient atmosphere.

2. Observations

Figure 1 shows a topographical map of the Brøggerbreen. Meteorological observa-

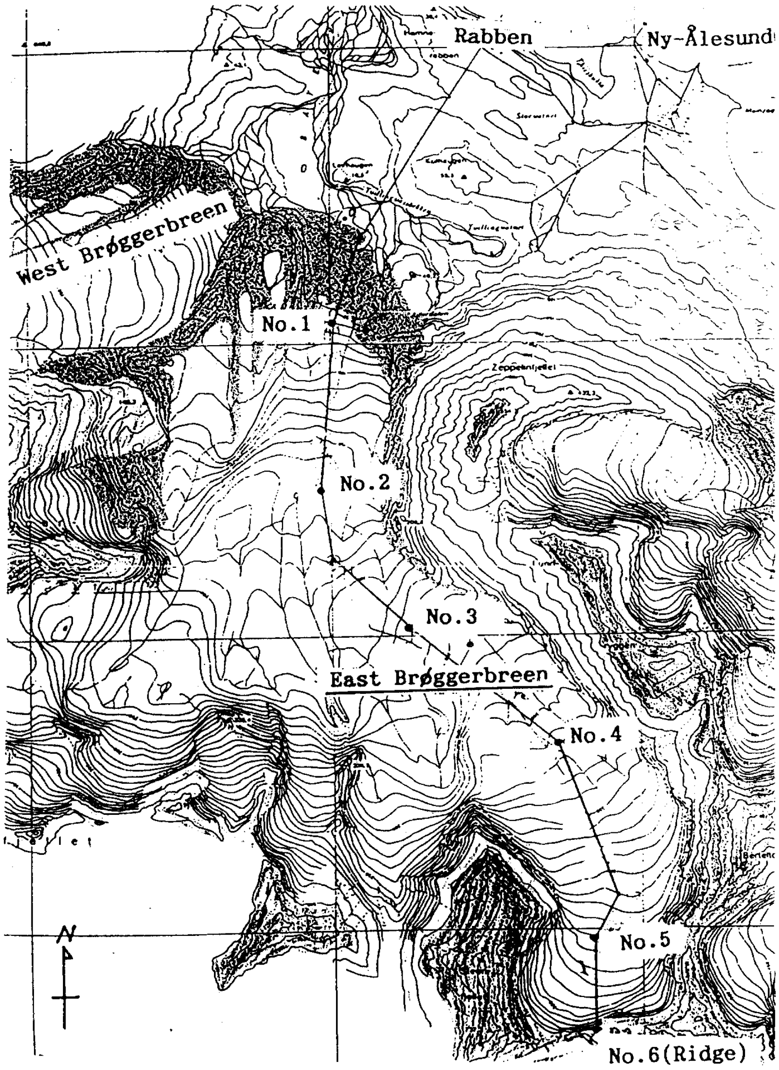

Fig. 1. Topographical map of the Brøggerbreen.

tions were carried out at six points distributed logitudinally over the slope of the Brøggerbreen. The uppermost observation point (570 m a.s.l.) was on a ridge of the surrounding mountains and the lowest observa-tion point (60 m a.s.l.) was near the glacier snout. The longitudinal cross section is shown in Fig. 2. Air temperature, wind speed and direction, solar radiation and surface radiative temperature were observed and recorded in a data logger at intervals of 10 min. Glacier ablation was observed using ablation stakes near the meteorological observation points. The ablation at the Depot point was measured by careful observation of changes in surface height. Those measurements were done at intervals of a couple of days; thus, day-to-day changes of ablation were not available. However, regional differences can be seen in the data. Table 1 summarizes the observation sites and observed elements. The mean air temperature, mean wind speed and ablation are also summarized in Table 1.

Observations were done in August 1991. This period corresponds to the warmest period in 1991; thus, this study observed specific meteorological conditions of the short ablation season in Svalbard.

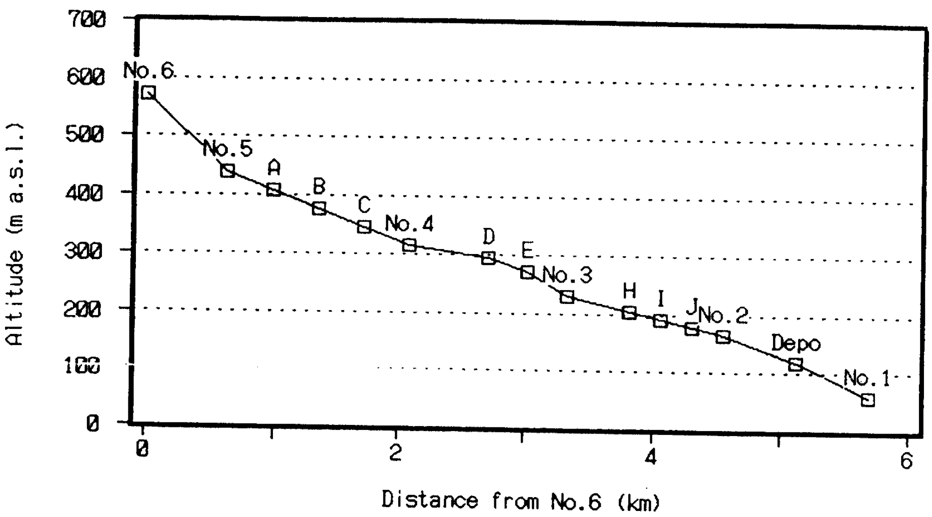

Fig. 2. Cross section of observation area over the Brøggerbreen.

Table 1. Observation sites and results.

Point	Distance from No. 6 (km)	Altitude (m a.s.l.)	Quantities	T (°C)	W_s (m/s)	A (cmW_{eq})
No. 1 (Snout)	5.6	60	T_a, W_s, W_d, R_h, R, A	7.2	3.0	2.3
Depo.	5.1	120	A			1.5
No. 2	4.5	165	A			0.5
No. 3	3.3	230	T_a, T_s, T_i, W_s, R_h, R, N, A	4.4	2.1	1.2
No. 4	2.1	315	A			1.3
No. 5	0.6	440	T_a, T_s, T_i, W_s, R, N, A	4.5	2.2	1.5
No. 6 (Ridge)	0	570	T_a, W_s, W_d	3.5	1.5	—

T_a: air temperature, T_s: snow temperature, T_i: surface temperature, W_s: wind speed, W_d: wind direction, R_h: relative humidity, R: global radiation, N: net radiation, A: ablation (also A–J on the map). Meteorological observations were taken at intervals of 10 min. Glacier ablation was measured every day at most points.

3. Results of Observations

The maximum air temperature on August 12 is the record for 1991. Figure 3 shows temporal fluctuations of air temperature and wind speed. Air temperatures at every observation points fluctuate in phase (Fig. 3a). Although the average air temperature increases in the lower part of the glacier, the middle part (No. 3) of the glacier was observed to be cool as was the upper part (No. 5). Surface temperature was measured at Nos. 3 and 5 using an infrared radiative thermometer at intervals of 10 min. The surface temperature was almost 0°C throughout the observation period and there were no large fluctuations. This implies that ablation occurred almost continuously during the observation period.

Wind speed increased over the lower part of the Brøggerbreen compared to the upper part (Fig. 3b), however, wind speed at No. 3 was not large. In the upper part of the

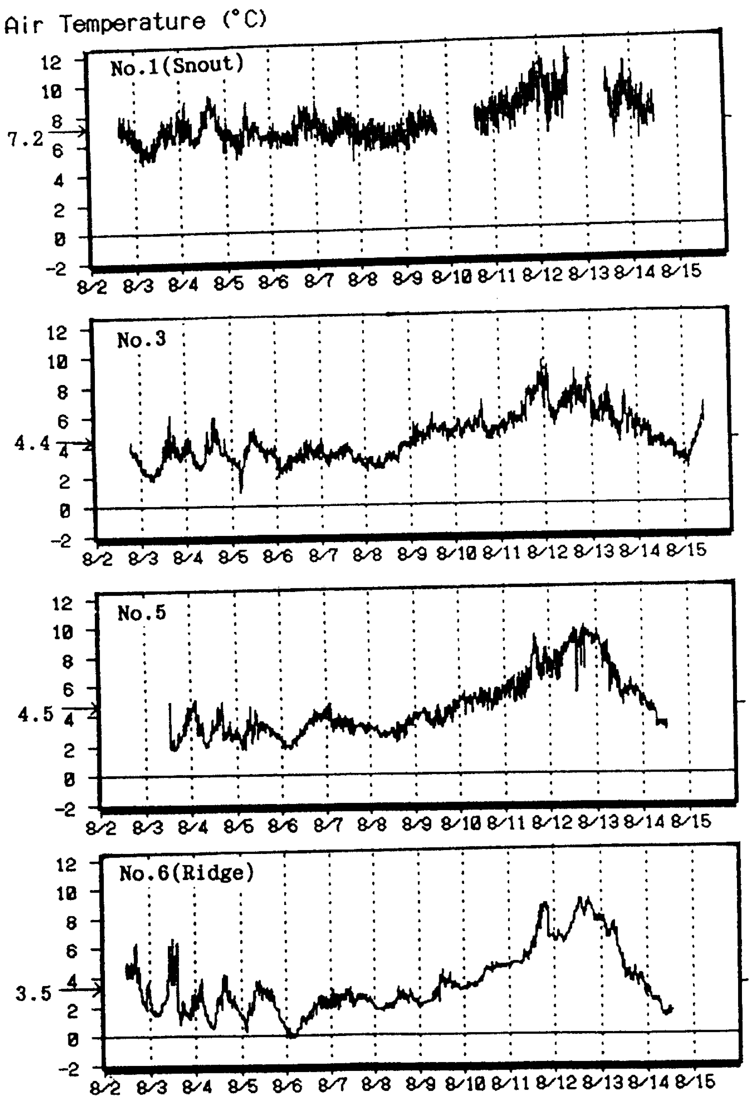

Fig. 3a. Variation of air temperature over the Brøggerbreen. The mean value is indicated at left.

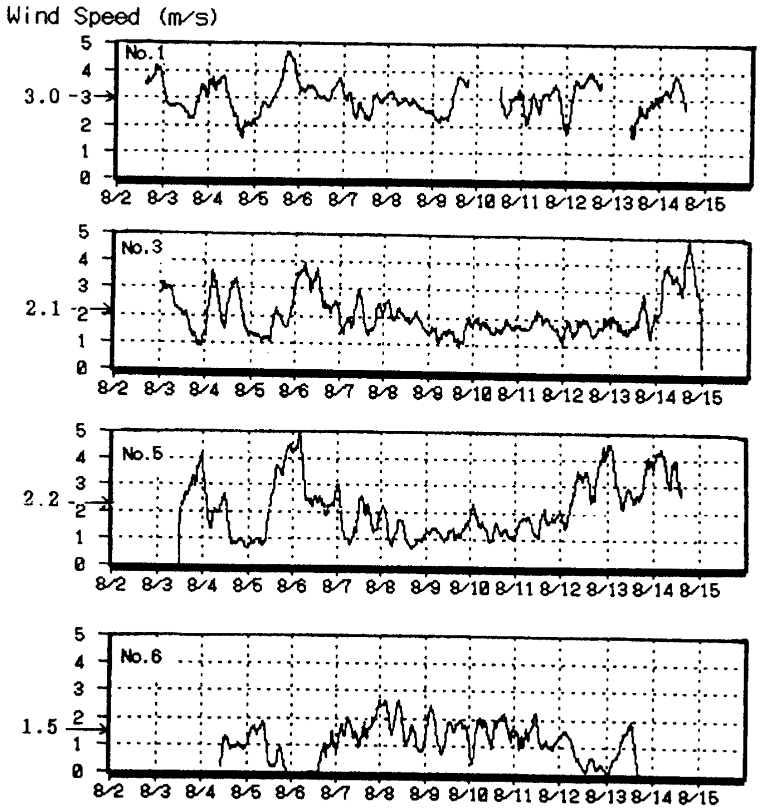

Fig. 3b. Same as Fig. 3a but for wind speed.

Brøggerbreen (Nos. 5 and 6), fluctuations of wind speed were complicated as they sometimes showed opposite tendencies, as seen on August 6 and 12 in Fig. 3b. Wind direction on the ridge (No. 6) was restricted to south or north, due to the direction of the ridge and surrounding peaks (Fig. 1). Based on Fig. 3b, the wind over the ridge (No. 6) is considered to affect the glacier wind in the valley around No. 5; however, this effect is not evaluated in the present study.

Ablation was observed on the Brøggerbreen. Results are summarized in Table 1. Large ablation was observed near the snout of the Brøggerbreen. Ablation shows a weak tendency to decrease from the upper part to the middle part around No. 2. Figures 4a and 4b show the longitudinal variations of mean air temperature (Fig. 4a), mean wind speed (Fig. 4a) and mean ablation (Fig. 4b). The mean air temperatures at Nos. 1, 5 and 6 fit on the same line which indicates a vertical temperature gradient (lapse rate) of 0.73°C/100 m (Fig. 4a). Air temperature at No. 3 was lower than this line and the wind speed was small at No. 3. Ablation was small around the area of 200 m a.s.l. where weaker wind and colder conditions than expected were observed.

4. Discussion

4.1. Local variations of temperature

Lapse rate was calculated from the temperature differences between the ridge (No.

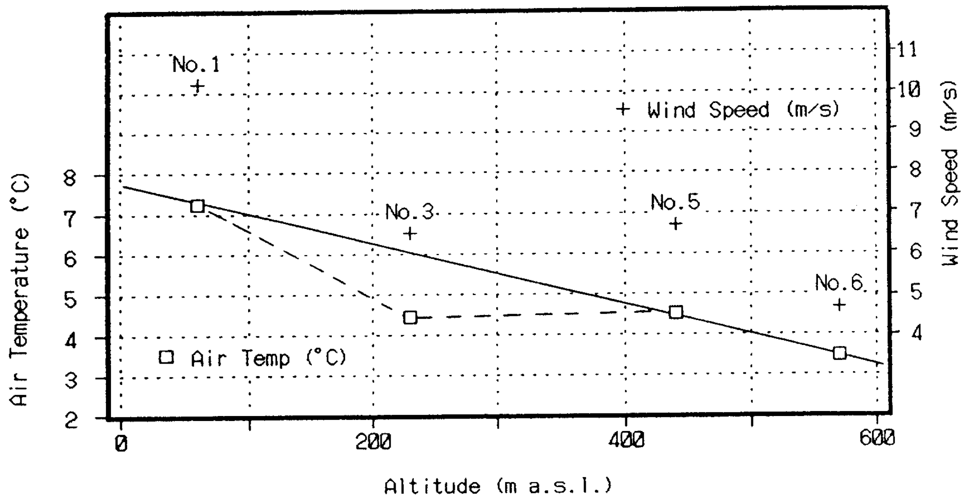

Fig. 4a. Longitudinal distributions of mean temperature and mean wind speed over the Brøggerbreen.

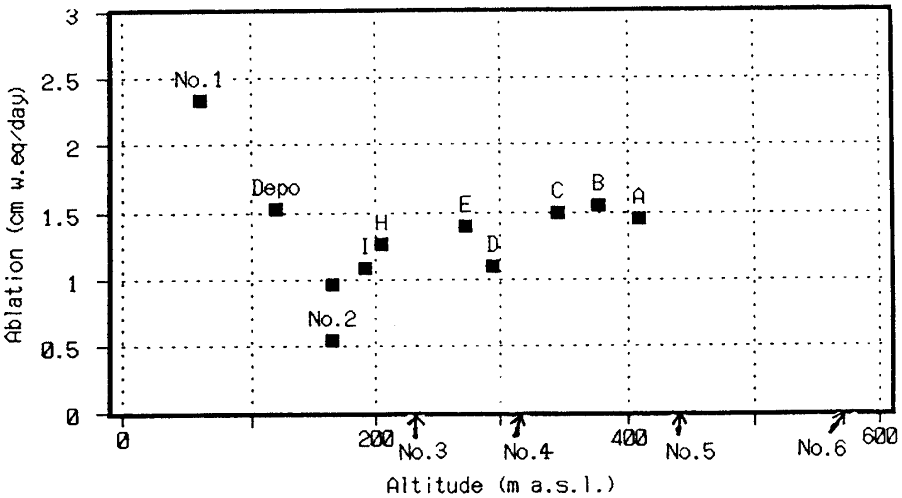

Fig. 4b. Longitudinal distribution of ablation.

6) and the snout (No. 1). Although the average lapse rate for the observation period was 0.73°C/100 m, it fluctuated considerably. Air temperature increases with the lapse rate between the ridge (No. 6: 570 m a.s.l.) and the upper part of the glacier (No. 5: 440 m a.s.l)(Fig. 5a). T_{obs} is the observed air temperature at No. 5, and T_{cal} is the calculated value using the air temperature at No. 6 and the lapse rate calculated from air temperatures at No. 1 and No. 6.

In the middle part of the glacier around No. 3, the air layer near the surface was cooled. The air temperature in the middle part was lower than that estimated using the lapse rate (No. 3 in Fig. 5b). Air seems to be cooled by blowing over the cold surface between No. 5 and No. 3.

From differences of T_{cal} and T_{obs} at No. 3, the influence of sensible heat on the glacier surface was evaluated. The air could be cooled by blowing over the cold surface

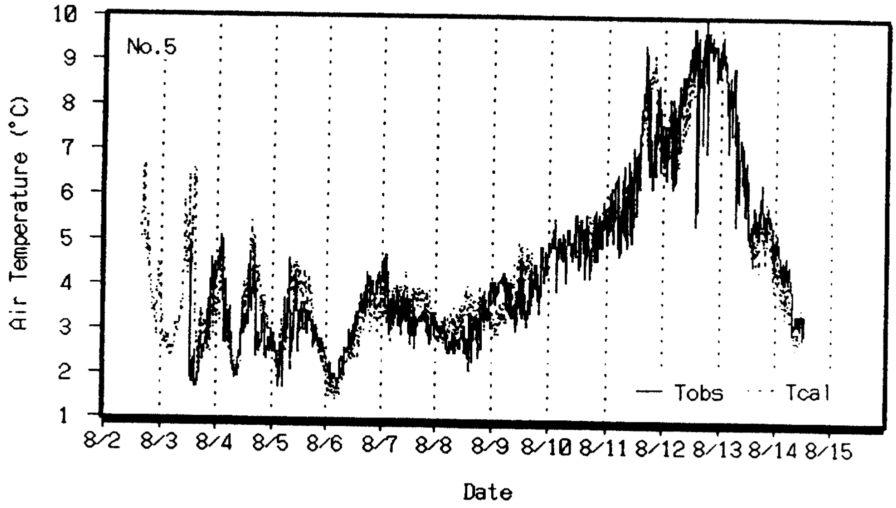

Fig. 5a. Observed air temperature at No. 5 and calculated air temperature using the lapse rate which is obtained from temperature differences between No. 6 and No. 1.

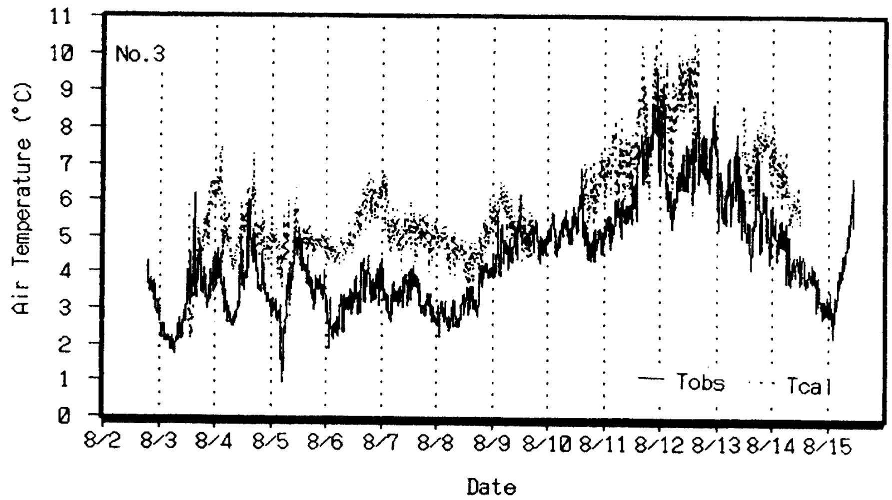

Fig. 5b. Same as Fig. 5a but for No. 3.

with a rate of 0.05–0.1°C/100 m of slope, from the temperature estimated from the lapse rate between No. 1 and No. 6. In a rare case heating between No. 5 and No. 3 was observed. In this case, strong solar radiation was also observed.

T_{cal} for No. 1 was also obtained from air temperature at No. 3 using the lapse rate as in Fig. 5. T_{cal} at No. 1 was smaller than T_{obs}. This shows that the air temperature increased greatly when the air approached the snout of the Brøggerbreen. In order for the air temperature at No. 1 to fit on the lapse rate line in Fig. 4a, air temperature needs to increase at the rate of 1.6°C/100 m between No. 3 and No. 1. The large increase of air temperature in the lower parts was considered to occur due to mixing of warmer air from the area surrounding the glacier. The local lapse rate between No. 3 and No. 1 was too large (1.6°C/100 m) to be produced by the adiabatic heating by subsidence.

4.2. *Wind fluctuation and instability*

Temporal fluctuations of wind speed in the middle part were observed to be associated with changes in the lapse rate (Fig. 6). The wind was strong when the temperature difference between No. 1 and No. 6 was large. This relationship can be seen in the middle part (No. 3) of the glacier; however, wind speeds at No. 5 and No. 1 show different fluctuations. These areas seem to be affected by the wind field over the ridge and in the fjord, respectively. OHATA (1989) reported on model calculations of glacier wind with various temperature conditions. He showed that wind speed is large when the air temperature in the surrounding area outside of the thermal influence of the glacier is large or its atmospheric condition is unstable. Wind speed is large when the lapse rate is large (No. 6). As the lapse rate is calculated between No. 1 (snout) and No. 6 (ridge), this lapse rate is a measure of instability of the ambient atmosphere. However, wind speed near the glacier snout does not change with the lapse rate between No. 1 and No. 6. Near the snout, the glacier wind system seems to be disturbed by the surrounding air circulation out side of the Brøggerbreen.

There are regional differences in wind speed over the glacier. Wind speed was small

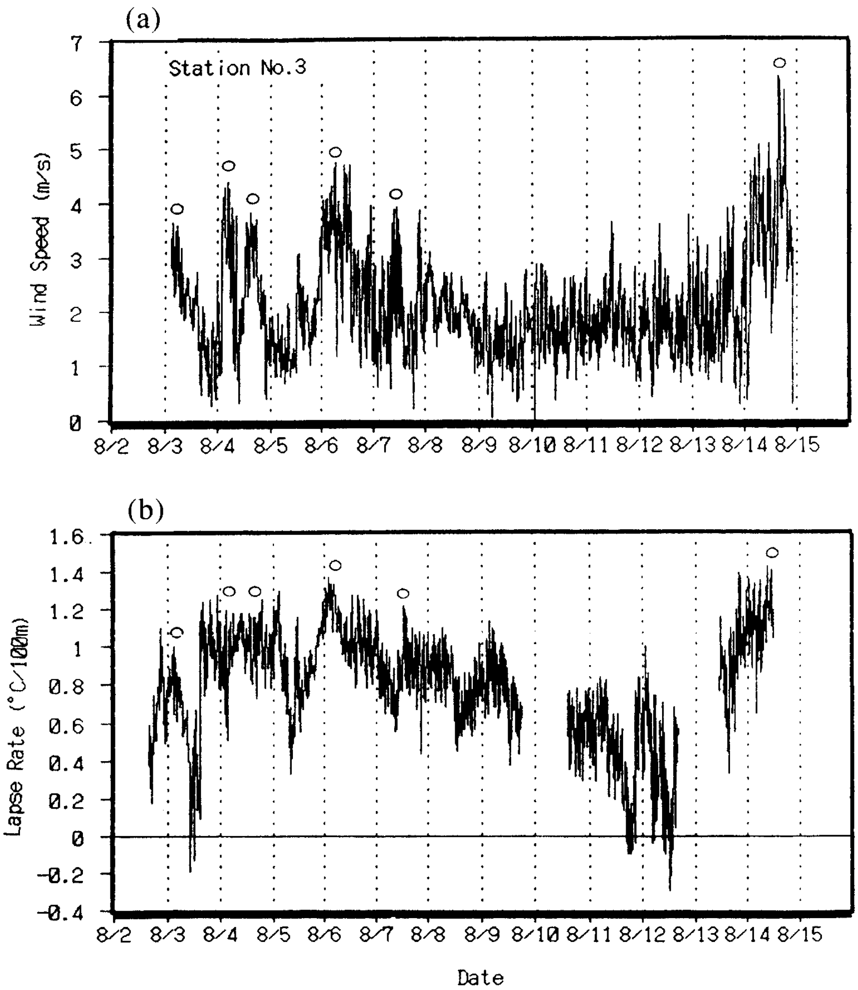

Fig. 6. Comparisons of (a) wind speed at No. 3 and (b) lapse rate.

in the middle part and then increased in the lower part of the glacier. Change of slope may be an effective cause of wind variation. There is a small ice rise in the lower-middle part of the Brøggerbreen (Figs. 1 and 2). The relatively flat area in the middle part could be a cause of weaker wind. Weak wind and lower temperature reduce the ablation, thus maintaining the ice rise.

4.3. Local variation of glacier ablation

Although air temperature is lower in the upper part (No. 5) of the Brøggerbreen, ablation was not small (Fig. 4). Where the glacier wind starts, air in the glacier wind exchanges heat with the colder glacier surface. This exchange cools the air above the glacier and heats the glacier surface. In the middle part, cooled air from the upper part blows and reduces the ablation. The wind speed decreases towards the middle part. Convergence of surface air can occur in this area if the width of the glacier wind does not change much. Weaker wind reduces the transport of sensible heat from the atmosphere to the glacier surface when the air temperature is low.

The opposite case is expected in the lower part of the glacier where the wind speed increases towards the glacier snout. In this case, subsidence or inflow of wind from neighboring glaciers and snow patches are expected. The glacier wind thickness and streamlines should be investigated. There seems to be considerable mixing with surrounding warmer air since the local lapse rate between No. 3 and No. 1 was 1.6°C/100 m on average.

HAGEN and LIESTØL (1990) also observed large ablation near the snout of the Brøggerbreen. They mentioned that the topographical conditions cause the lower part of the Brøggerbreen to be exposed to the wind field in the fjord. This may cause an increase of air temperature near the snout; however, strong wind from the glacier also affects this area. Therefore, local circulations must occur to produce warm and strong wind over the snout area of the Brøggerbreen.

5. Conclusions

Air temperature at No. 6, No. 5 and No. 1 changes with the average lapse rate of 0.73°C/100 m; air temperature at No. 3 is colder than estimated by this lapse rate. Wind speed was small and ablation was also small in this middle part (Nos. 3 and 2), and hereafter it increases greatly towards the glacier snout. Strong mixture in the lower part of the Brøggerbreen could occur and produce large increase of air temperature near the snout. This is seen as the large lapse rate 1.6°C/100 m defined locally between No. 3 and No. 1. Figure 7 shows a sketch of the processes discussed in the present paper.

Fluctuation of wind speed in the middle part of the glacier (No. 3) reflected that of the instantaneous lapse rate obtained from temperatures on the ridge and near the snout of the Brøggerbreen. Instability of the atmosphere appears to cause the changes in glacier wind speed.

Although local variation of insolation over the glacier should be investigated, glacier wind also affects local variations of ablation. Due to the regional variations of glacier ablation, the slope becomes steeper in the lower part and flatter in the middle part. This changes the slope; in turn, it increases the longitudinal variation of wind speed.

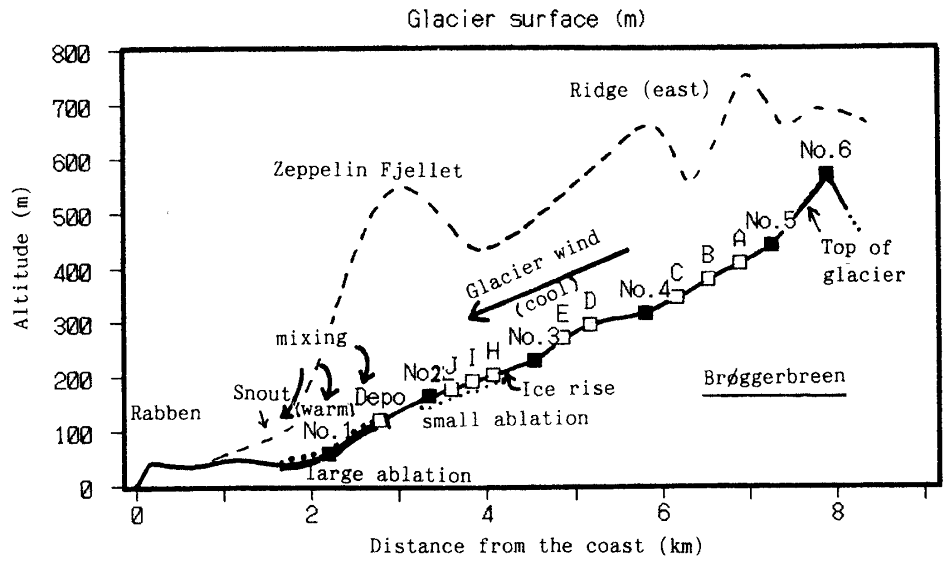

Fig. 7. Sketch of longitudinal variations of glacial conditions over the Brøggerbreen.

There can exist an interaction between the surface variation and the wind field over the Brøggerbreen, although the whole system is under influences of broader environmental changes.

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